N73-31948

NASA TECHNICAL NOTE

NASA TN D-7351

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CORNERING CHARACTERISTICS OF A 40 × 14-16 TYPE VII AIRCRAFT TIRE AND A COMPARISON WITH CHARACTERISTICS OF A C40 × 14-21 CANTILEVER AIRCRAFT TIRE

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • OCTOBER 1973

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TN D-7351		

4. Title and Subtitle	5. Report Date
CORNERING CHARACTERISTICS OF A 40 × 14-16 TYPE VII AIRCRAFT TIRE AND A COMPARISON WITH CHARACTERISTICS OF A C40 × 14-21 CANTILEVER AIRCRAFT TIRE	October 1973
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
John A. Tanner and Robert C. Dreher	L-9046
	10. Work Unit No.
9. Performing Organization Name and Address	501-38-12-02
NASA Langley Research Center Hampton, Va. 23665	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Note
National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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The results of this investigation indicated that the cornering capability of the 40 × 14-16 type VII aircraft tire is degraded by high ground speeds, thin-film lubrication and tire hydroplaning effects on the wet surfaces, and brake torque. The cornering capability is greatly diminished when locked-wheel skids are encountered.

A comparison of the cornering characteristics of the 40 × 14-16 type VII aircraft tire and those of the C40 × 14-21 cantilever aircraft tire presented in NASA TN D-7203 indicated that the cornering capability of the cantilever tire is greater than the cornering capability of the conventional tire on the dry surface but is less than that of the conventional tire on the wet surfaces at high ground speeds. At 100 knots, the conventional tire develops a higher drag-force friction coefficient than the cantilever tire for most test conditions.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Aircraft tire High-speed cornering Friction coefficients	Unclassified – Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified	25	Domestic, \$2.75 Foreign, \$5.25

*For sale by the National Technical Information Service, Springfield, Virginia 22151

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SUMMARY

An investigation was conducted at the Langley aircraft landing loads and traction facility to determine the cornering characteristics of a 40 × 14-16 type VII aircraft tire. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds from 5 to 100 knots, both with and without braking.

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A comparison of the cornering characteristics of the 40 × 14-16 type VII aircraft tire and those of the C40 × 14-21 cantilever aircraft tire presented in NASA TN D-7203 indicated that the cornering capability of the cantilever tire is greater than the cornering capability of the conventional tire on the dry surface but is less than that of the conventional tire on the wet surfaces at high ground speeds. At 100 knots, the conventional tire develops a higher drag-force friction coefficient than the cantilever tire for most test conditions.

INTRODUCTION

As the costs and program risks associated with aircraft flight tests increase rapidly, many airplane manufacturers are relying on computer simulations to play a major role in the development of new airplane designs and modifications. Recently the scope of these computer studies has expanded to include landing-gear design problems. One of the consequences of this computer technology boom has been an increased demand for experimental data on the aircraft tire high-speed lateral-friction characteristics needed to define aircraft cornering capabilities and to update tire shimmy analyses. References 1 to 5 are

examples of early research papers which present the results of studies of the low-speed yawed-rolling characteristics of several aircraft tires. Reference 6, a more recent paper, presents the results of a study of the high-speed cornering characteristics of a C40 × 14-21 aircraft tire of cantilever design. However, no data are available on the high-speed cornering characteristics of the conventional 40 × 14-16 aircraft tire which is used on many of the same commercial and military aircraft as the cantilever tire.

The purpose of this paper is to present the results of an investigation conducted at the Langley aircraft landing loads and traction facility to define the cornering characteristics of a 40 × 14-16 type VII aircraft tire and to compare the results of this investigation with the cornering characteristics of the C40 × 14-21 cantilever tire presented in reference 6. These characteristics, which include the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° at ground speeds from 5 to 100 knots, both with and without braking.

SYMBOLS

Measurements and calculations were made in U.S. Customary Units and converted to SI units. Values are given in both SI and U.S. Customary Units.

$B_{T,D}$	brake torque measured on dry surface
T_z	self-alining torque
V	ground speed
μ_d	drag-force friction coefficient parallel to direction of motion
μ_s	cornering-force friction coefficient perpendicular to direction of motion
Ψ	wheel yaw angle

APPARATUS AND TEST PROCEDURE

Test Tires

The tires used in this investigation were size 40 × 14-16, type VII, bias-ply aircraft tires of 22 ply rating and had a rated maximum speed of 200 knots (1 knot = 0.5144 m/sec). Photographs of the conventional tire and of a cantilever tire of similar outside dimension

are presented in figure 1. The conventional tire is shown before testing, and the cantilever tire is shown after testing. Throughout this investigation, the tire inflation pressure was maintained at 1070 kPa (155 psi) and the vertical load was fixed at a nominal value of 111 kN (25 000 lb). (These loading conditions are the same as those used during the cantilever tire tests of ref. 6.) The tire was replaced when approximately 50 percent of the original tread was worn off.

The cross section of the cantilever tire and that of the conventional tire are shown in figure 2. As illustrated, the larger rim opening available with the cantilever tire provides space for a larger brake assembly without increasing the tire outside diameter. An additional advertised feature of the cantilever tire is its "run-flat" capability. In the event of complete loss of inflation pressure, the tire purportedly collapses symmetrically without folding to one side as does the conventional tire.

Runway Surface Conditions

For the tests described in this paper, approximately 174 m (570 ft) of a concrete test section were divided into three subsections to provide tire cornering data on dry, damp, and flooded surfaces. The first 76 m (250 ft) of the test section were maintained dry; the next 37 m (120 ft) were dampened (no visible standing water); and the remaining 61 m (200 ft) were surrounded by a dam and flooded with water to a depth of approximately 0.8 cm (0.32 in.). Thus, during one test, data were obtained for the three surface wetness conditions. The dry subsection was necessarily long to provide time for full wheel spinup and, for those tests which involve braking, time for brake actuation. The concrete surface in the test section had a light broom finish which was somewhat smoother than that of most operational concrete runways.

Test Facility

The investigation was performed at the Langley aircraft landing loads and traction facility, which is described in reference 7, and utilized the main test carriage which weighs approximately 534 kN (120 000 lb). Figure 3 is a photograph of the carriage with the installed test wheel assembly, and figure 4 is a closeup view of the wheel and shows details of the instrumented dynamometer which supports the wheel and measures the various axle loadings. In figure 5 is presented a schematic of the dynamometer instrumentation which consisted of load beams to measure vertical, drag, and lateral forces and links to measure brake torque, all at the wheel axle. Additional instrumentation was provided to measure brake pressure, wheel angular displacement, and carriage horizontal displacement. Continuous time histories of the output of the instrumentation were recorded by an oscillograph mounted on the test carriage. For this investigation, a landing-gear strut was not employed because the dynamometer was needed to measure the forces and moments accurately.

Test Procedure

The test procedure consisted of setting the dynamometer and tire assembly to the preselected yaw angle, propelling or towing the test carriage to the desired ground speed, releasing the drop-test fixture to apply the preselected vertical load to the tire, and monitoring the output from the onboard instrumentation. The yaw angle was increased in 5° increments from 0° to 20° and ground speeds ranged from 5 to 100 knots. To obtain a speed of 5 knots, the test carriage was towed by a ground vehicle; for higher speeds, the carriage was propelled by the hydraulic jet as described in reference 7. In tests which incorporated wheel braking, the brake was actuated after the vertical load had been applied and the tire was in a steady-state rolling condition. Time histories of the output of the instrumentation were recorded as the tire passed consecutively over the dry, damp, and flooded test surfaces.

40 × 14-16 TYPE VII AIRCRAFT TIRE RESULTS

Time histories of forces in the vertical, drag, and side directions; brake torque; and wheel angular velocity were recorded on an oscillograph throughout each test. These time histories were used to compute steady-state values of the cornering-force friction coefficient μ_s perpendicular to the direction of motion and the drag-force friction coefficient μ_d parallel to the direction of motion. The self-alining torque T_z is a ground torque in the footprint which is developed about the vertical or steering axis of the wheel and which alines the tire with the direction of motion when positive; it is computed from the load transfer between the two drag-load beams shown in figure 5. In this section are discussed the effects of yaw angle, ground speed, brake torque, and surface wetness on the cornering characteristics of the 40 × 14-16 type VII aircraft tire.

Effect of Yaw Angle

The effect of yaw angle on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire is presented in figure 6 for various ground speeds, surface-wetness conditions, and braking torques.

Cornering-force friction coefficient.- Data which describe the effect of yaw angle on the cornering-force friction coefficient μ_s developed with and without braking are presented in figure 6. The brake torque values given in the figure were those measured on the dry surface; these same brake pressures were used in the tests on the damp and flooded surfaces. For the unbraked condition, the data presented in figure 6(a) indicate that, in general, μ_s increases with an increase in yaw angle, reaches a maximum value, and then decreases with further increases in Ψ. Increasing the ground speed reduces the value of μ_s, particularly at the higher yaw angle and on the wet surfaces. Furthermore, increasing the ground speed reduces the yaw angle at which maximum cornering is devel-

oped. Typically, the maximum cornering at 5 knots is developed at a yaw angle of approximately 15^{o}, whereas the maximum cornering at 100 knots appears to occur at about 10^{o}. The data presented in figures 6(b) and 6(c) indicate that the braking effort of these tests resulted in a locked-wheel skid on the flooded surface at all yaw angles with corresponding negligible values of μ_s. Partial wheel spindown occurred with light braking on the damp surface at a yaw angle of 15^{o} and locked-wheel skids occurred at all yaw angles on that surface during heavy braking.

Drag-force friction coefficient.- Figure 6 also shows the effect of yaw angle on the drag-force friction coefficient μ_d. The data obtained without brake torque (fig. 6(a)) indicate that μ_d generally increases with an increase in yaw angle and decreases with increasing ground speed on all three surfaces, particularly at high yaw angles. Data obtained with light and heavy braking (figs. 6(b) and 6(c)) also indicate that μ_d increases with increasing yaw angle but, as expected, at a higher level at a ground speed of 5 knots. At 100 knots, either wheel spindown or wheel lockup reduces the value of μ_d to about 0.1 or less on the damp and flooded surfaces.

Self-alining torque.- The effect of yaw angle on the self-alining torque T_z is also shown in figure 6. The data indicate that for most test conditions presented, T_z generally increases from zero to a maximum positive value at a 5^{o} yaw angle and then decreases with a further increase in yaw angle. The self-alining torque generally decreases when the ground speed is increased, especially on the wet surfaces. The increase in T_z for the high yaw angles at 100 knots on the damp surface for the unbraked and lightly braked tire is due to nonuniform surface wetness. Negative values of T_z are noted for the unbraked tire (fig. 6(a)) at high yaw angles, particularly on the dry surface. Larger negative values of T_z are generally noted for the tire on all three surfaces with the introduction of braking (figs. 6(b) and 6(c)) and the crossover between positive (self-alining) and negative (divergent) values generally occurs at smaller yaw angles. At high ground speeds under heavy braking, no positive self-alining torque is observed at any yaw angle for all three surfaces.

Effect of Ground Speed

The effect of ground speed on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire is presented in figure 7. These data were obtained with the tire freely rolling (unbraked) at a yaw angle of 10^{o} over a speed range from 5 to 100 knots.

Cornering-force friction coefficient.- Figure 7 shows that ground speed has little effect on the cornering-force friction coefficient μ_s on the dry surface; however, on the wet surfaces μ_s decreases significantly with an increase in ground speed. On the damp surface, the reduction in μ_s is attributed to thin-film lubrication (sometimes referred to as viscous hydroplaning); on the flooded surface, the reduction is attributed

to dynamic hydroplaning effects. The calculated hydroplaning speed for this tire is 112 knots (ref. 8).

Drag-force friction coefficient.- The drag-force friction coefficient μ_d for the unbraked tire is the result of tire rolling resistance and the drag-force component generated by the yawed-rolling condition. The data presented in figure 7 indicate that μ_d is unaffected by variations in ground speed on the dry surface and decreases only slightly with an increase in ground speed on the damp and flooded surfaces.

Self-alining torque.- The self-alining torque T_z is shown in figure 7 to reach peak values at approximately 30 knots and then gradually to decrease with a further increase in ground speed for most test conditions.

Effect of Brake Torque

Appropriate data from figure 6 are presented in figure 8 to show more clearly the effect of brake torque on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire. The data in figure 8 were obtained at 100 knots.

Cornering-force friction coefficient.- The data presented in figure 8 indicate that on a dry runway the maximum value of the cornering-force friction coefficient μ_s occurs at a 10° yaw angle and decreases about 15 or 20 percent when the brake torque is increased from 0 to 11 524 N-m (8500 ft-lb). Heavy braking at a 15° yaw angle causes a partial wheel spindown. Similarly, on the damp surface the maximum value of μ_s for the unbraked wheel and lightly braked wheel occurs at a 10° yaw angle, but the effect of brake torque is more pronounced. Light braking reduces the maximum value of μ_s by about 30 percent, and heavy braking results in locked-wheel skids and a nearly complete loss of μ_s. On the flooded surface with heavy braking, the value of μ_s never exceeds 0.08.

Drag-force friction coefficient.- Figure 8 shows that the drag-force friction coefficient μ_d increases with an increase in brake torque on the dry surface for all yaw angles. Heavy braking on the damp surface results in locked-wheel skids. On the flooded surface, brake torque has little effect on the magnitude of μ_d since both light braking and heavy braking cause locked-wheel skids.

Self-alining torque.- The self-alining torque T_z is shown in figure 8 to decrease as the brake torque is increased on the dry and damp surfaces and to be affected very little on the flooded surface.

Effect of Surface Wetness

To better illustrate the effect of surface wetness on the cornering characteristics of the 40 × 14-16 type VII aircraft tire, selected data of figure 6 are presented in figure 9.

These data were obtained at a ground speed of 100 knots with no brake torque and covered a range of yaw angles from 0° to 20°.

Cornering-force friction coefficient.- The maximum value of cornering-force friction coefficient μ_s is shown to reduce appreciably when the surface becomes wet. For the test conditions shown in figure 9, the damp surface causes a reduction in μ_s of about 50 percent from the dry-surface value for most yaw angles. When the surface is flooded, the percent reduction in μ_s from the dry-surface values is even greater. The reductions are attributed to tire hydroplaning effects.

Drag-force friction coefficient.- Figure 9 shows that surface wetness reduces the value of the drag-force friction coefficient μ_d from the dry-surface value for yaw angles above 10°. This reduction is also attributed to tire hydroplaning effects. At the lower yaw angles, increased fluid drag causes μ_d to be slightly higher on the flooded surface than on the dry and damp surfaces.

COMPARISON OF CORNERING CHARACTERISTICS OF 40 × 14-16 TYPE VII AIRCRAFT TIRE AND C40 × 14-21 CANTILEVER AIRCRAFT TIRE

A comparison of the cornering characteristics of the 40 × 14-16 type VII aircraft tire and the C40 × 14-21 cantilever aircraft tire is presented in this section. The faired data describing the variation of cornering-force friction coefficient μ_s, drag-force friction coefficient μ_d, and self-alining torque T_z with yaw angle and ground speed for the cantilever tire were obtained from reference 6.

Effect of Yaw Angle

The effect of yaw angle on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire and of the C40 × 14-21 cantilever aircraft tire is presented in figure 10 for various surface-wetness conditions and braking torques at a ground speed of 100 knots.

Cornering-force friction coefficient.- The unbraked yawed-rolling data presented in figure 10(a) and the lightly braked data presented in figure 10(b) indicate that on the dry surface the cantilever tire develops higher values of cornering-force friction coefficient μ_s than the conventional tire for yaw angles above approximately 5°. On the damp and flooded surfaces where hydroplaning effects have reduced the traction available the conventional tire is shown to develop the higher values of μ_s. The heavily braked data presented in figure 10(c) also indicate that the cantilever tire develops higher values of μ_s on the dry surface; however, on the wet surfaces, where locked-wheel skids were encountered for both tires, no significant differences are noted between the values of μ_s developed by the conventional and cantilever tires.

Drag-force friction coefficient.- The data presented in figure 10 indicate that the conventional tire generally develops higher values of drag-force friction coefficient μ_d than the cantilever tire for most test conditions. The one exception to this trend occurs on the damp surface during heavy braking. For the light braking tests, the higher values of μ_d for the conventional tire are attributed, in part, to the slightly larger brake torque values measured for that tire during the investigation.

Self-alining torque.- The unbraked data presented in figure 10(a) indicate that on the dry surface, the maximum positive value of self-alining torque T_z for both tires occurs at a 5^{o} yaw angle and decreases to negative values as Ψ is increased to 20^{o}. On the damp surface the maximum positive value of T_z occurs at approximately 10^{o} for both tires. As mentioned previously, the increase in T_z at the higher yaw angles noted for the conventional tire is attributed to nonuniform surface wetness. On the flooded surface the values of T_z for the conventional tire are slightly greater than for the cantilever tire. With the introduction of light braking, the data (fig. 10(b)) indicate that on the dry surface, the maximum positive value of T_z occurs at a 5^{o} yaw angle for both tires with the conventional tire developing the greater values. In addition, negative values of T_z are obtained at smaller yaw angles than with the unbraked tires. On the damp surface, negative values of T_z are noted at yaw angles above 5^{o} for the conventional tire and for all yaw angles for the cantilever tire. (As mentioned previously, the increase in T_z at the higher yaw angles observed for the conventional tire is attributed to nonuniform surface wetness.) On the flooded surface, T_z for both tires approaches negligible values. The data presented in figure 10(c) shows that with heavy braking, negative values of T_z are obtained for both tires on the dry and damp surface for all yaw angles. Negligible values of T_z are noted for both tires on the flooded surface.

Effect of Ground Speed

The effect of ground speed on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire and of the C40 × 14-21 cantilever aircraft tire is presented in figure 11. These data were obtained for both tires at a fixed yaw angle of 10^{o} with no braking and covered a speed range from 5 to 100 knots.

Cornering-force friction coefficient.- The faired data presented in figure 11 indicate that the values of cornering-force friction coefficient μ_s are generally higher for the cantilever tire than for the conventional tire on the dry and damp surfaces, and essentially no difference is noted in the μ_s values for the two tires on the flooded surfaces. These results indicate that the vulnerability of the cantilever tire to friction losses caused by tire hydroplaning effects noted earlier for a ground speed of 100 knots may not exist throughout the entire speed range.

Drag-force friction coefficient.- Data presented in figure 11 indicate that the values of drag-force friction coefficient μ_d are slightly higher for the conventional tire than for the cantilever tire for the test conditions shown, and that the values are affected very little by ground speed.

Self-alining torque.- Figure 11 indicates that the self-alining torque T_Z reaches a peak value for the conventional tire at approximately 30 knots on all three surfaces. No peaking in T_Z is noted for the cantilever tire. The figure also shows that the values of T_Z for the conventional tire are greater than or equal to those for the cantilever tire at all speeds on all three surfaces.

SUMMARY OF RESULTS

Tests were conducted at the Langley aircraft landing loads and traction facility to determine the cornering characteristics of a 40 × 14-16 type VII aircraft tire. These characteristics, which included the cornering-force and drag-force friction coefficients and self-alining torque, were obtained for the tire operating on dry, damp, and flooded runway surfaces over a range of yaw angles from 0° to 20° and at ground speeds from 5 to 100 knots, both with and without braking. The results from the tests of the 40 × 14-16 type VII aircraft tire are summarized as follows:

1. The cornering-force friction coefficient was shown (1) to increase with increasing yaw angle, to reach a peak value, and then to decrease with a further increase in yaw angle; (2) to decrease with an increase in ground speed, particularly on the wet surfaces; (3) to decrease significantly with increasing brake torque on wet surfaces at high speeds; and (4) to be negligible when locked-wheel skids were encountered.

2. The drag-force friction coefficient was shown (1) to increase slightly with an increase in yaw angle; (2) to decrease slightly with an increase in ground speed; and (3) to increase with increasing brake torque and then to decrease to a skidding value when a locked-wheel skid was encountered.

3. The self-alining torque was shown (1) to reach a maximum positive value at a 5° yaw angle with no brake torque; (2) to become negative with high yaw angles and/or brake torques; and (3) to be sensitive to nonuniform surface wetness.

A comparison of the cornering characteristics of the 40 × 14-16 type VII aircraft tire and those of the C40 × 14-21 cantilever aircraft tire presented in NASA TN D-7203 indicated that the cornering capability of the cantilever tire was greater than that of the conventional tire on the dry surface but was less than that of the conventional tire on the

wet surfaces at high ground speeds. At 100 knots, the conventional tire developed a higher drag-force friction coefficient than the cantilever tire for most test conditions.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., July 31, 1973.

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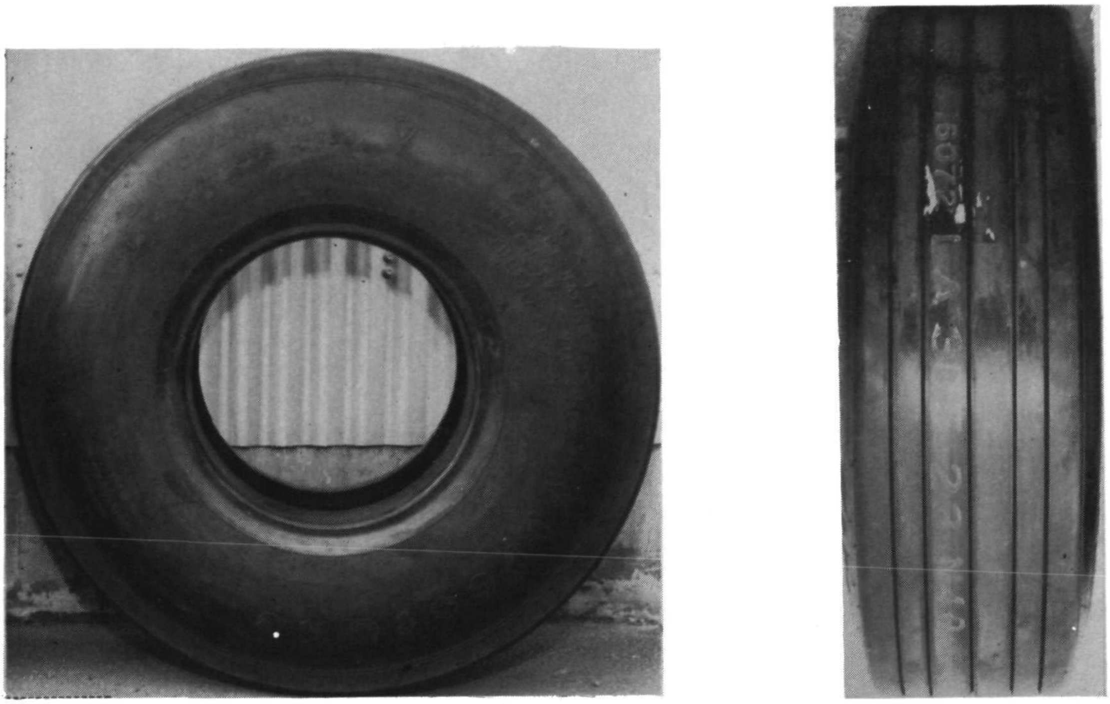
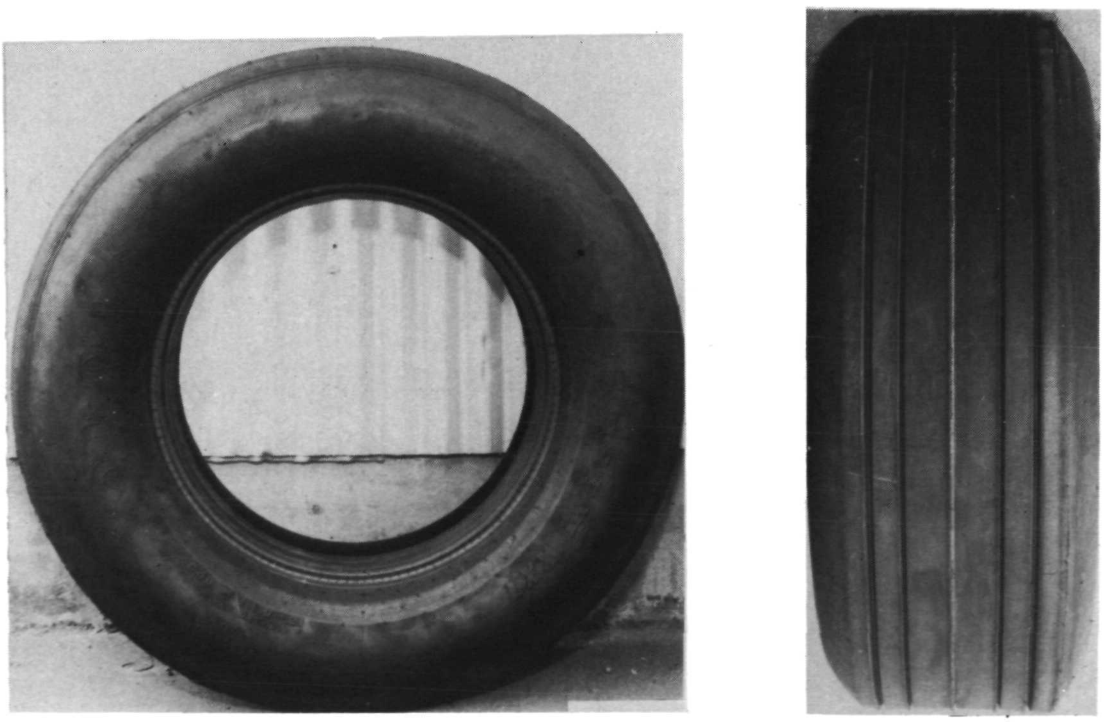


(a) Conventional tire.



(b) Cantilever tire. L-73-6818

Figure 1.- Conventional 40 × 14-16 type VII test tire and C40 × 14-21 cantilever test tire.

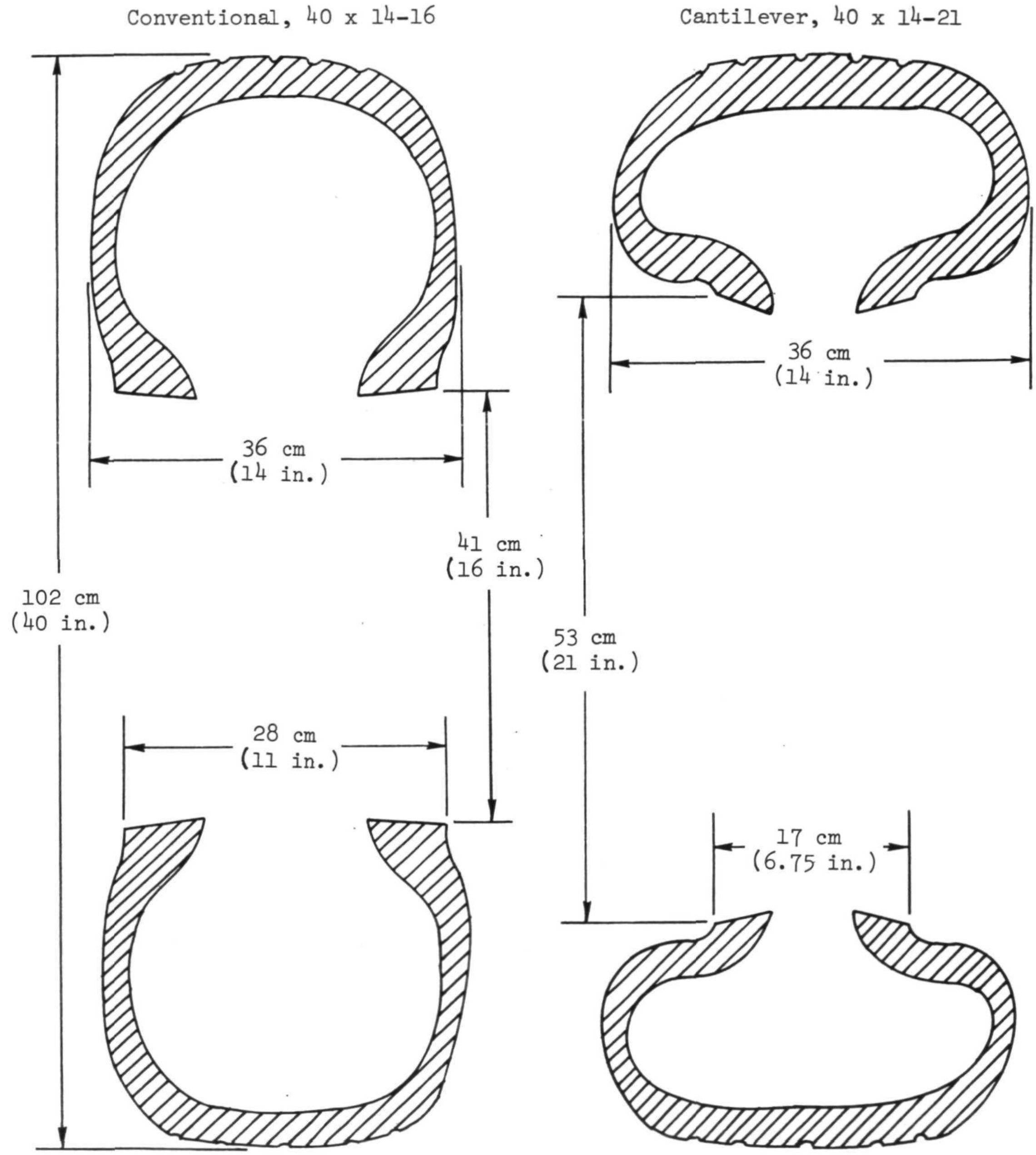


Figure 2.- Conventional and cantilever tire cross sections.

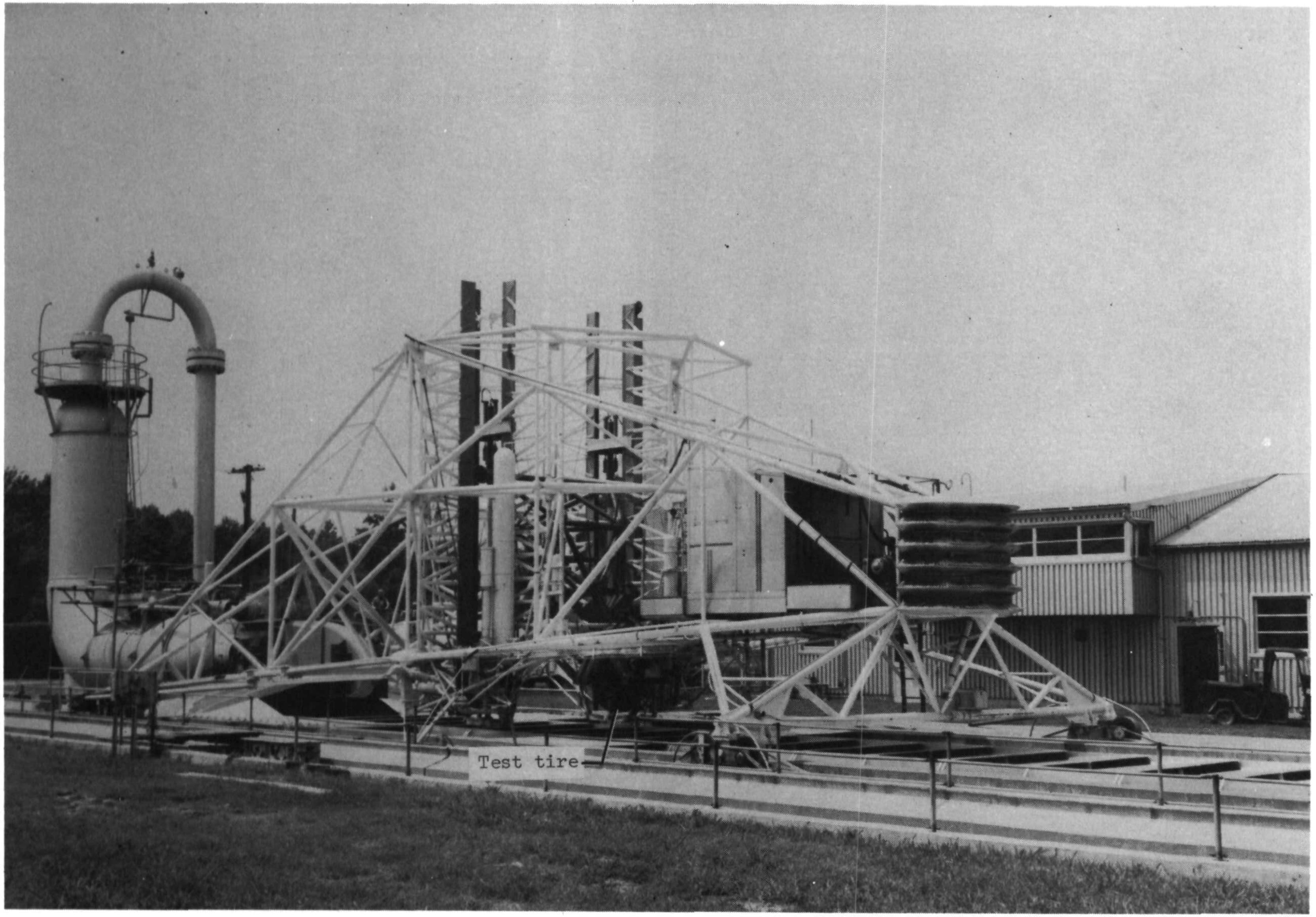


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Figure 3.- Main test carriage at Langley aircraft landing loads and traction facility.

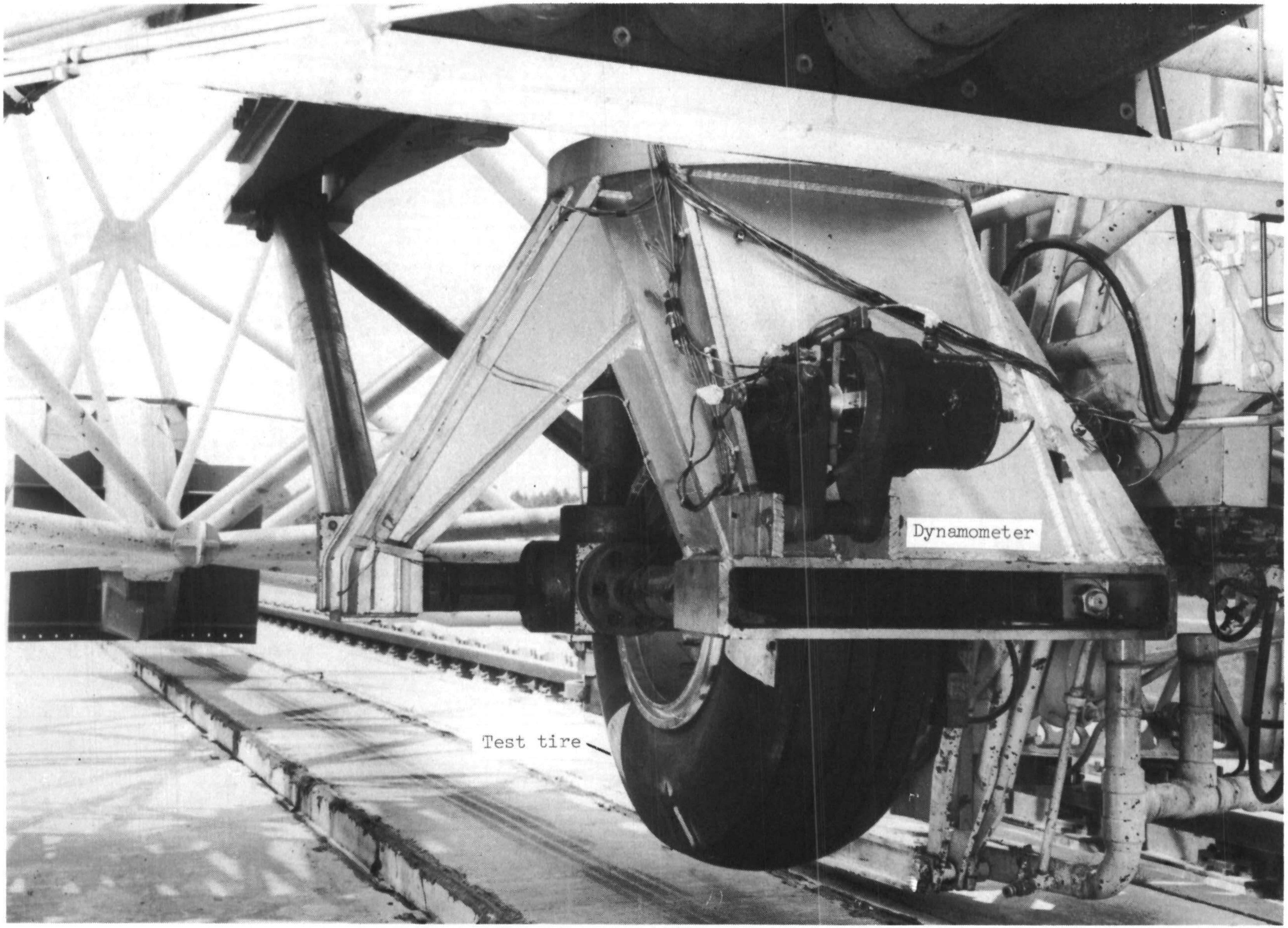

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Figure 4.- Dynamometer used in tests.

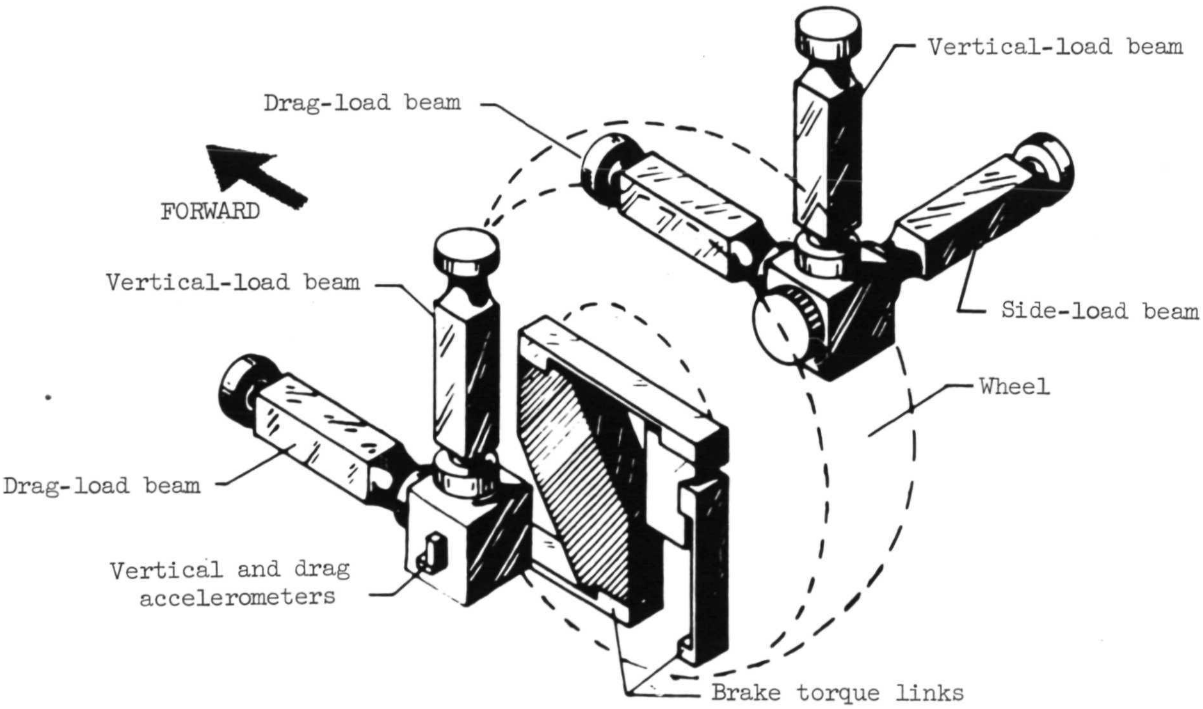
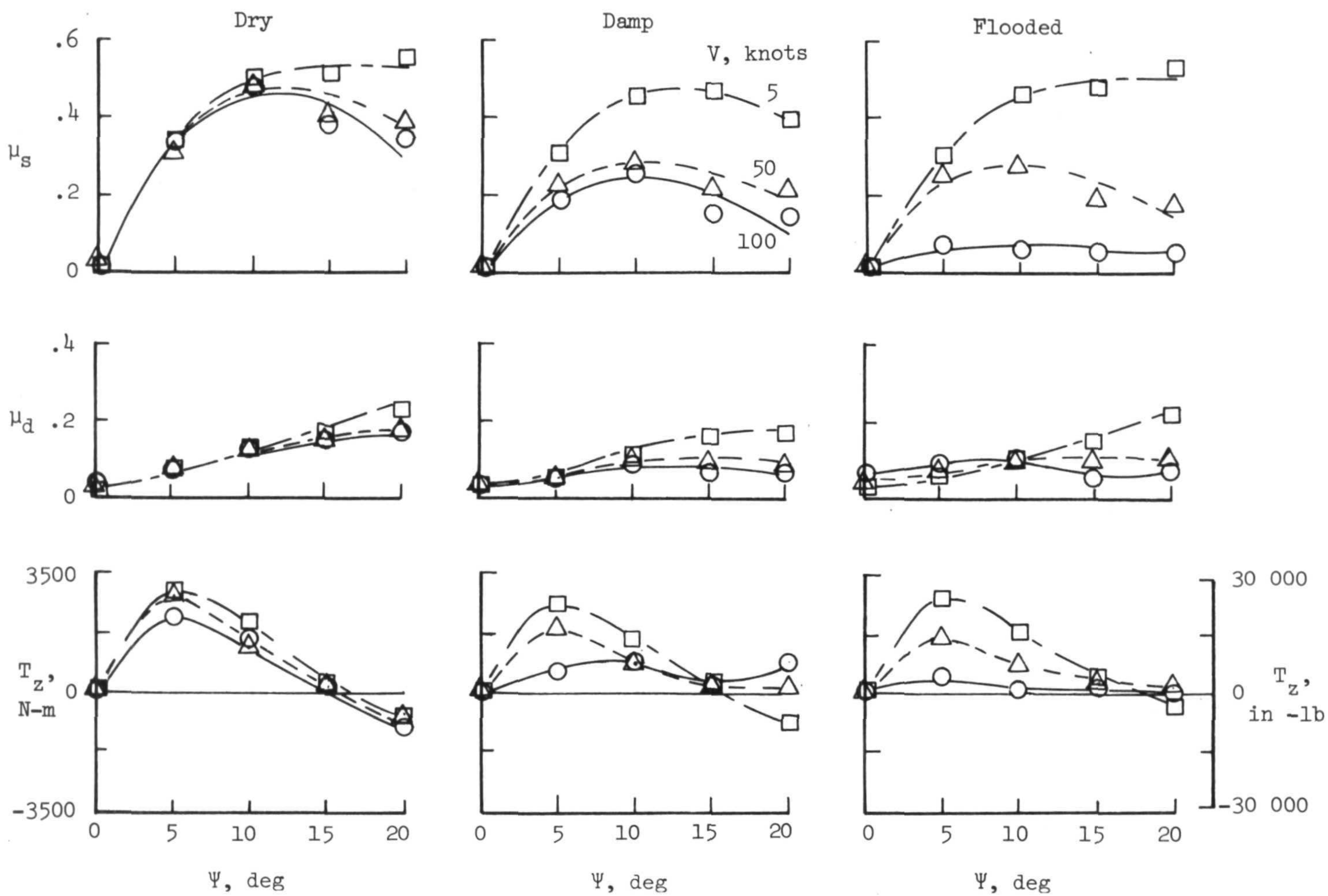
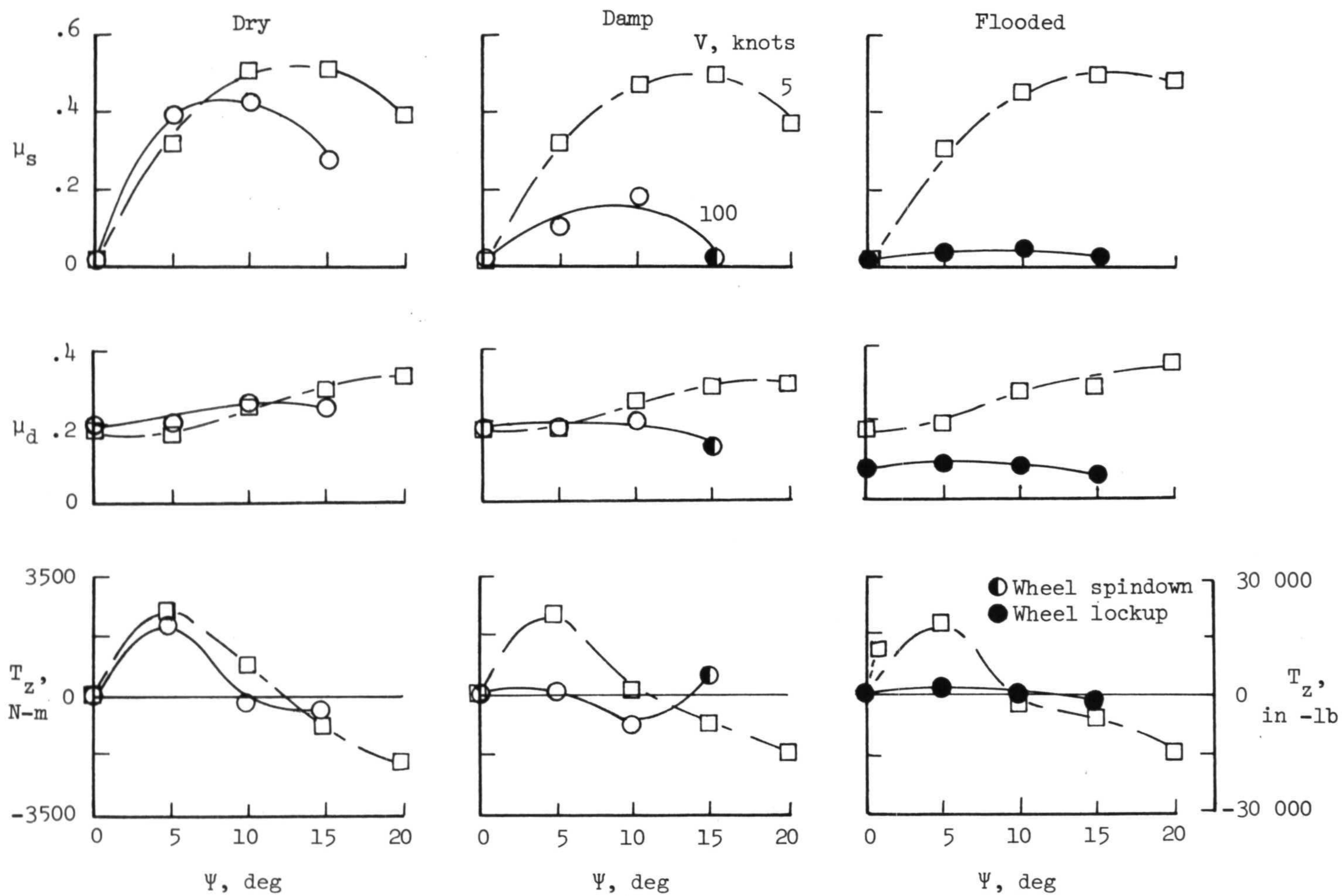


Figure 5.- Schematic of dynamometer showing location of load beams.



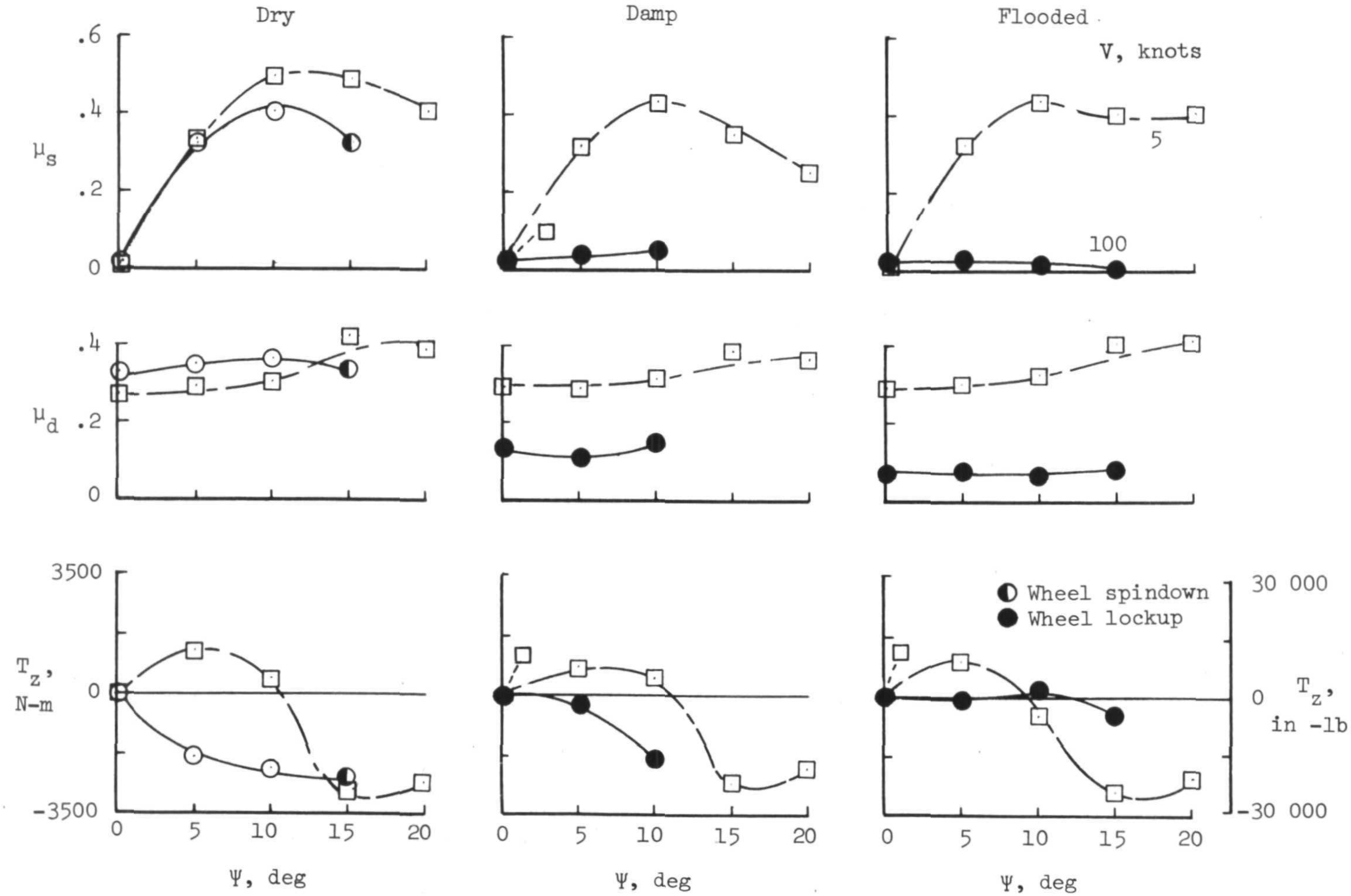
(a) Unbraked; $B_{T,D} = 0$.

Figure 6.- Effect of yaw angle on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire.



(b) Light braking; $B_{T,D}$ = 5830 N-m (4300 ft-lb).

Figure 6.- Continued.



(c) Heavy braking; $B_{T,D}$ = 11 524 N-m (8500 ft-lb).

Figure 6.- Concluded.

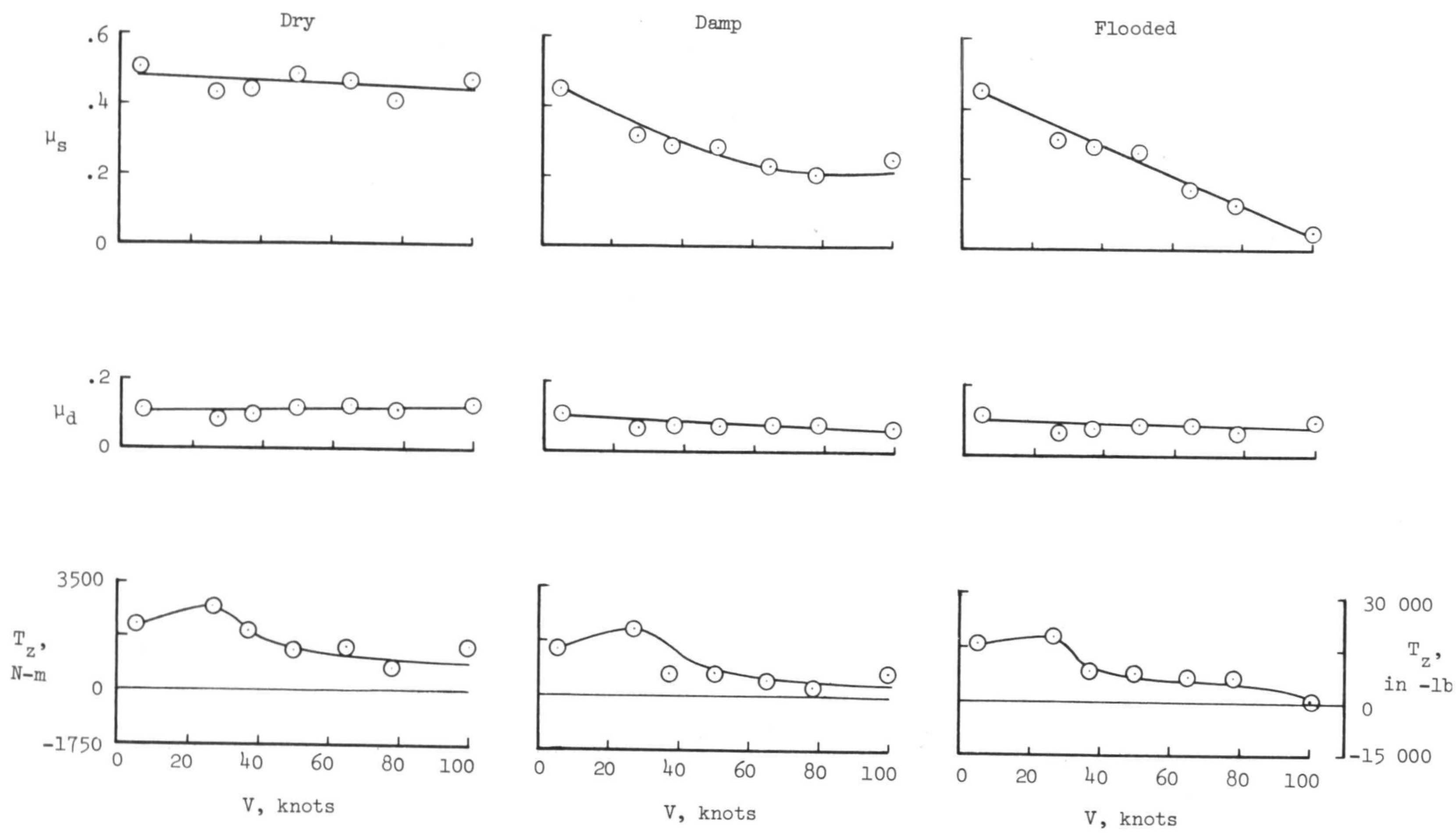


Figure 7.- Effect of ground speed on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire. Brake torque, 0; yaw angle, 10°.

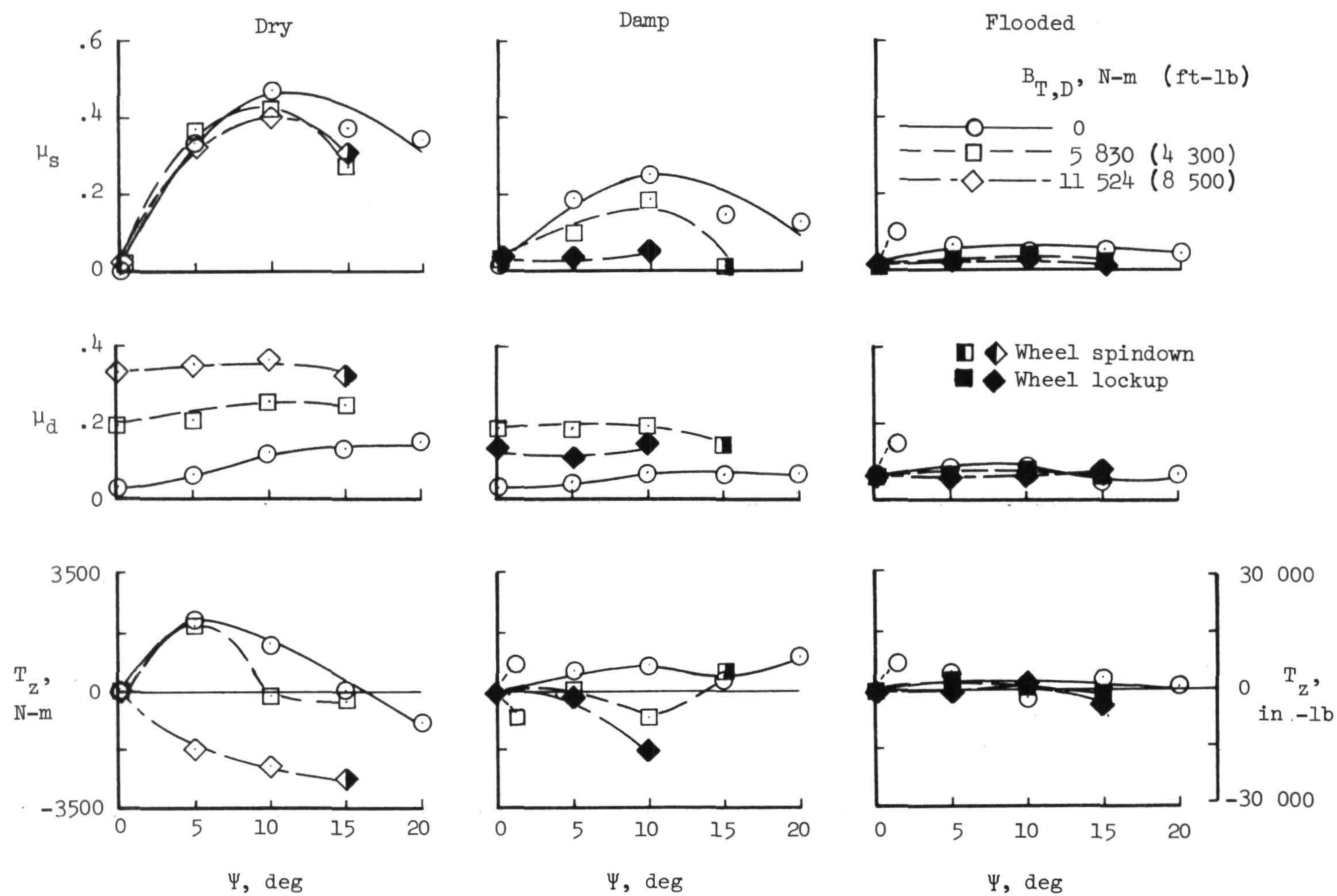


Figure 8.- Effect of brake torque on the cornering-force and drag-force friction coefficients and self-alining torque of the 40 × 14-16 type VII aircraft tire. Ground speed, 100 knots.

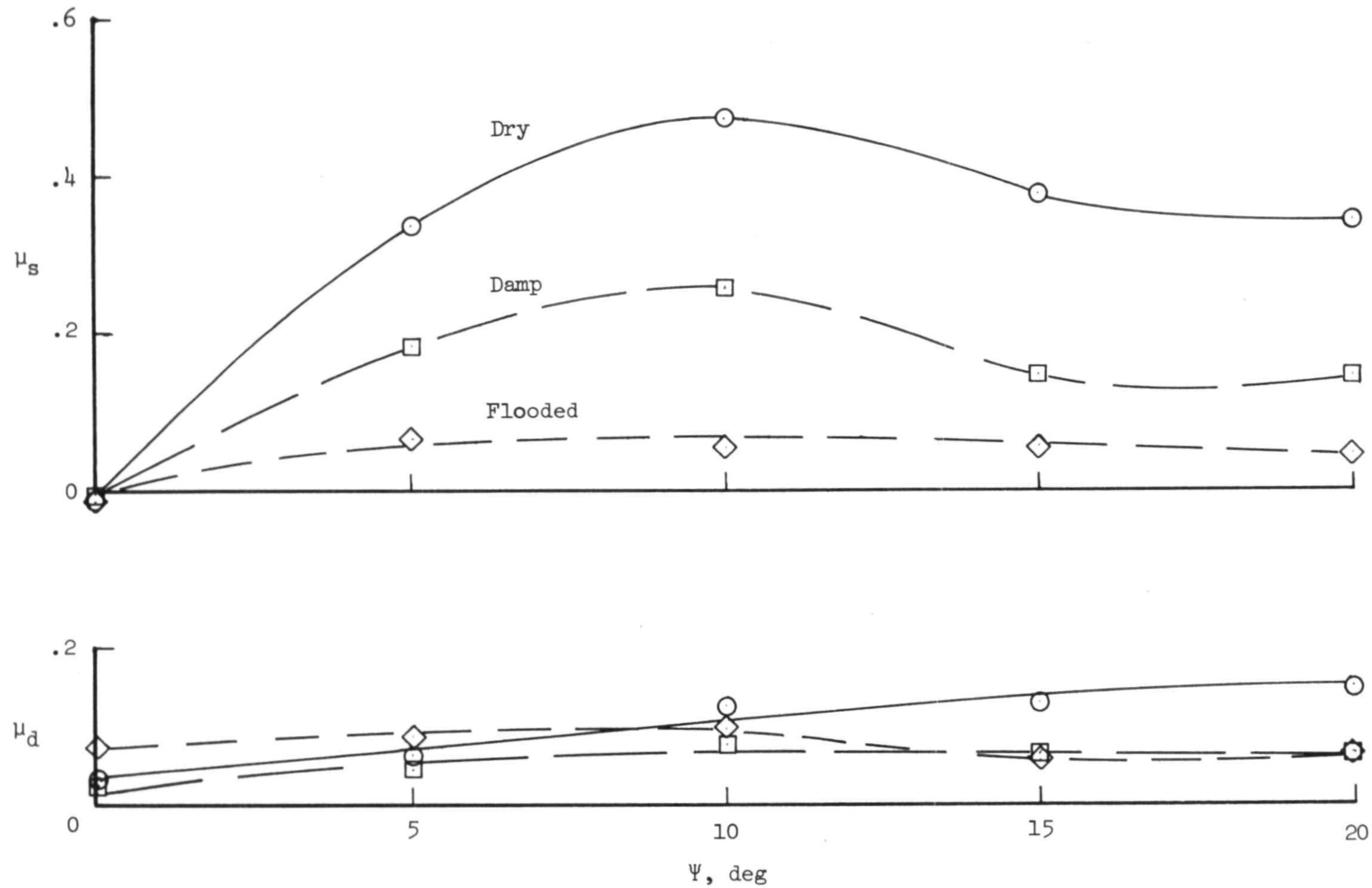
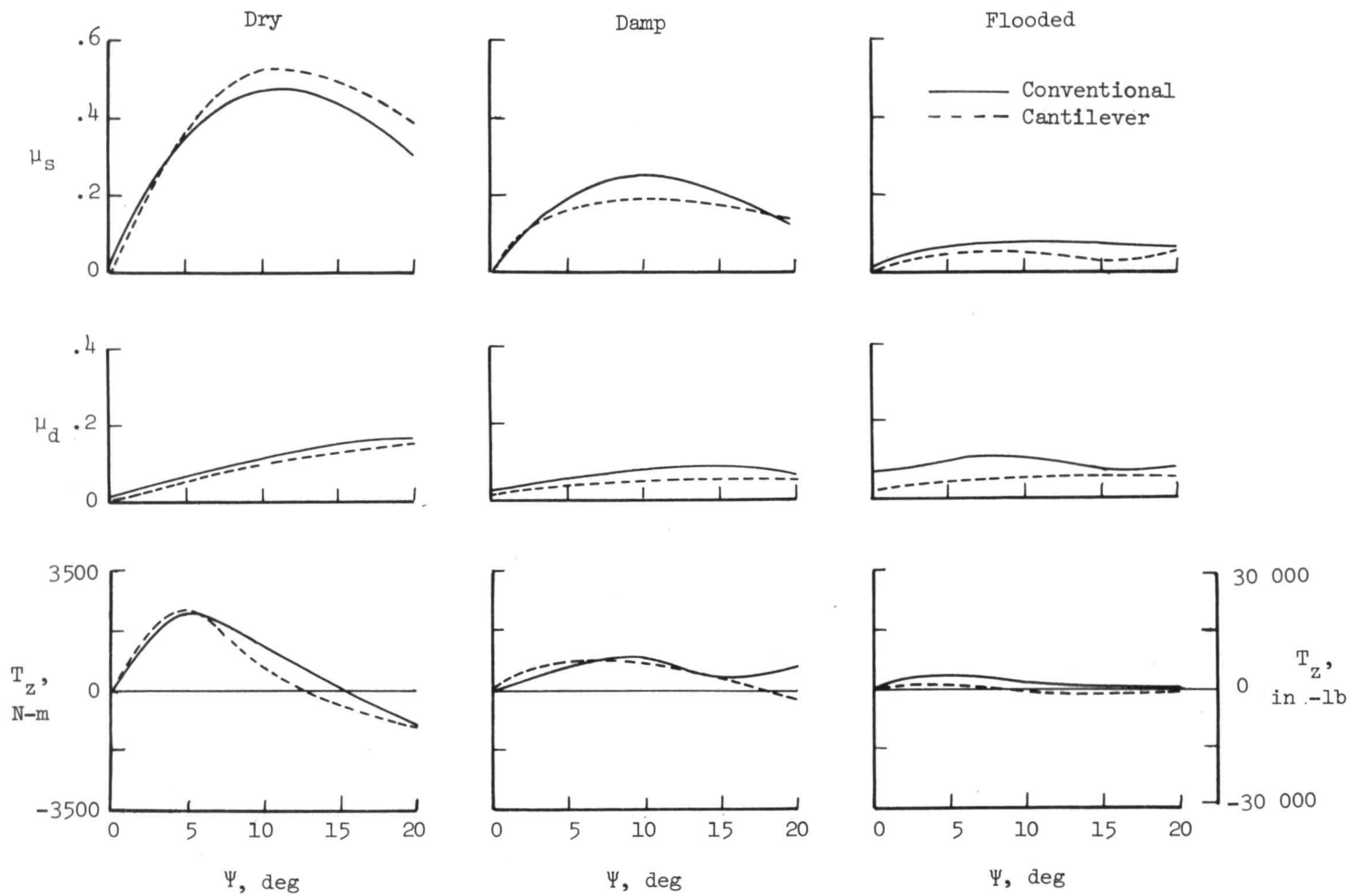
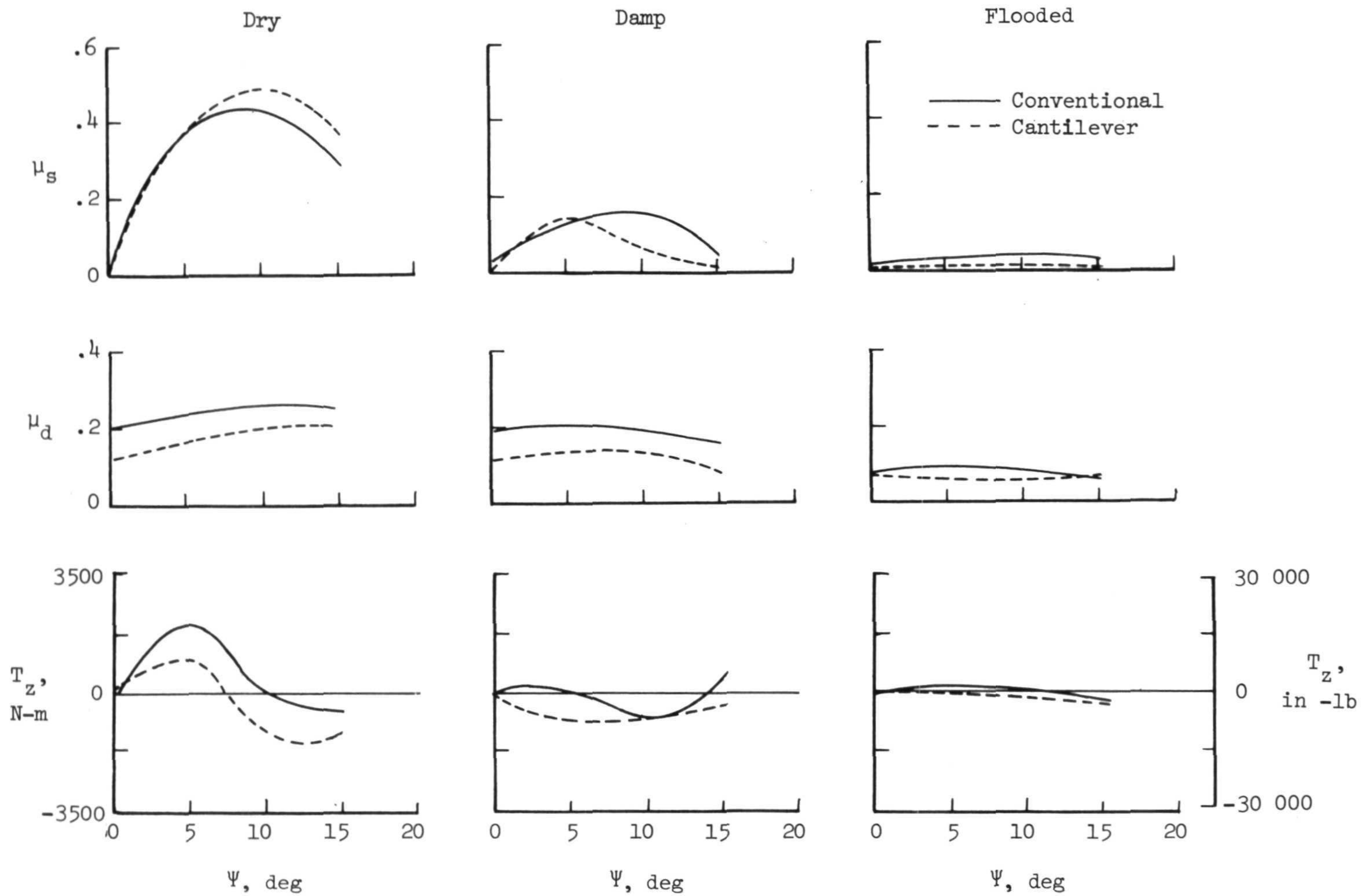


Figure 9.- Effect of surface wetness on the cornering-force and drag-force friction coefficients at various yaw angles for the 40 × 14-16 type VII aircraft tire. Ground speed, 100 knots; brake torque, 0.



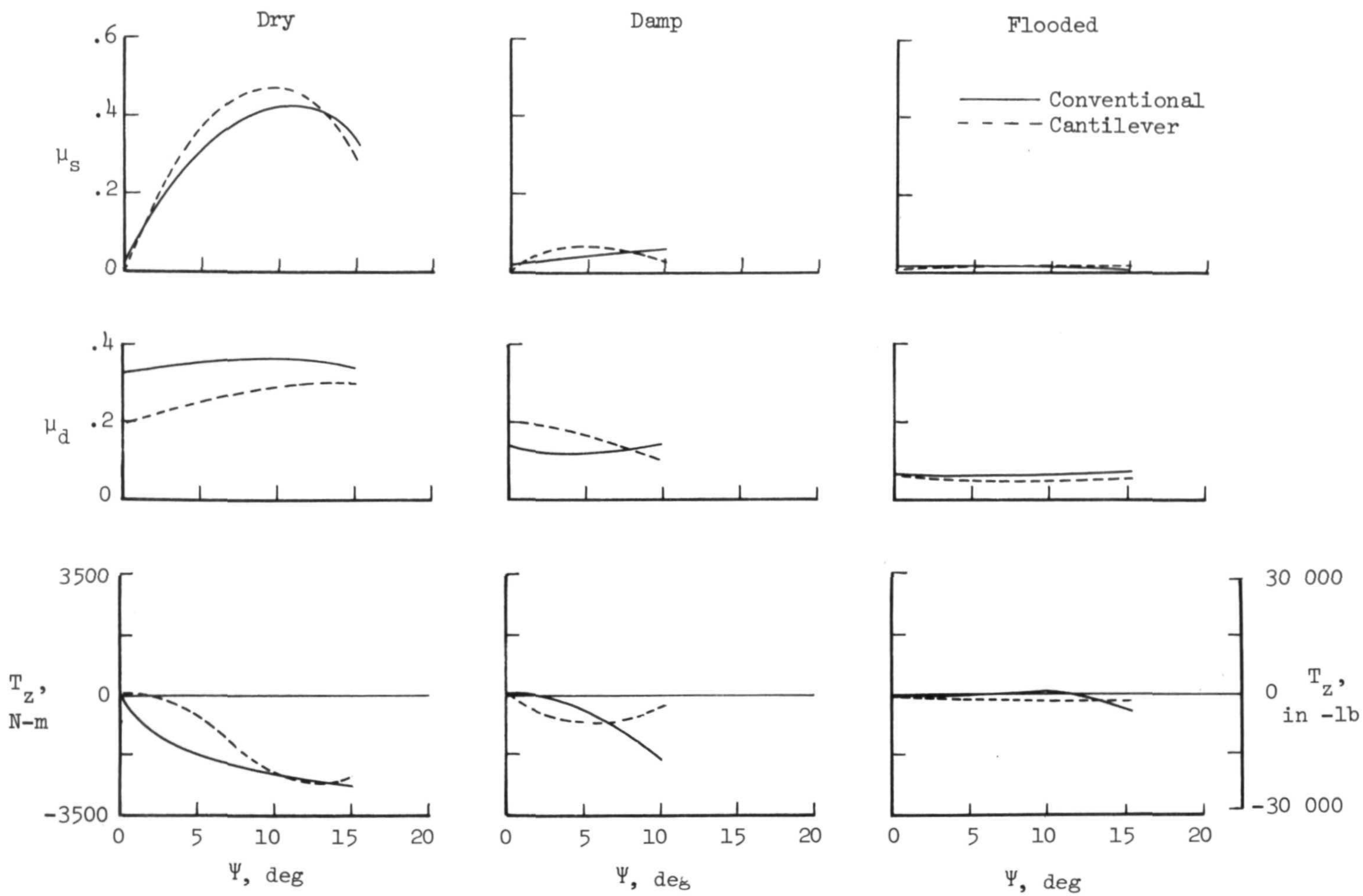
(a) Unbraked; $B_{T,D} = 0$.

Figure 10.- Effect of yaw angle on cornering-force and drag-force friction coefficients and self-alining torque of the conventional 40 × 14-16 type VII aircraft tire and of the C40 × 14-21 cantilever aircraft tire on dry, damp, and flooded surfaces. Ground speed, 100 knots.



(b) Light braking; $B_{T,D}$ = 5830 N-m (4300 ft-lb) for conventional tire and 5423 N-m (4000 ft-lb) for cantilever tire.

Figure 10.- Continued.



(c) Heavy braking; $B_{T,D}$ = 11 524 N-m (8500 ft-lb) for conventional tire and 12 202 N-m (9000 ft-lb) for cantilever tire.

Figure 10.- Concluded.

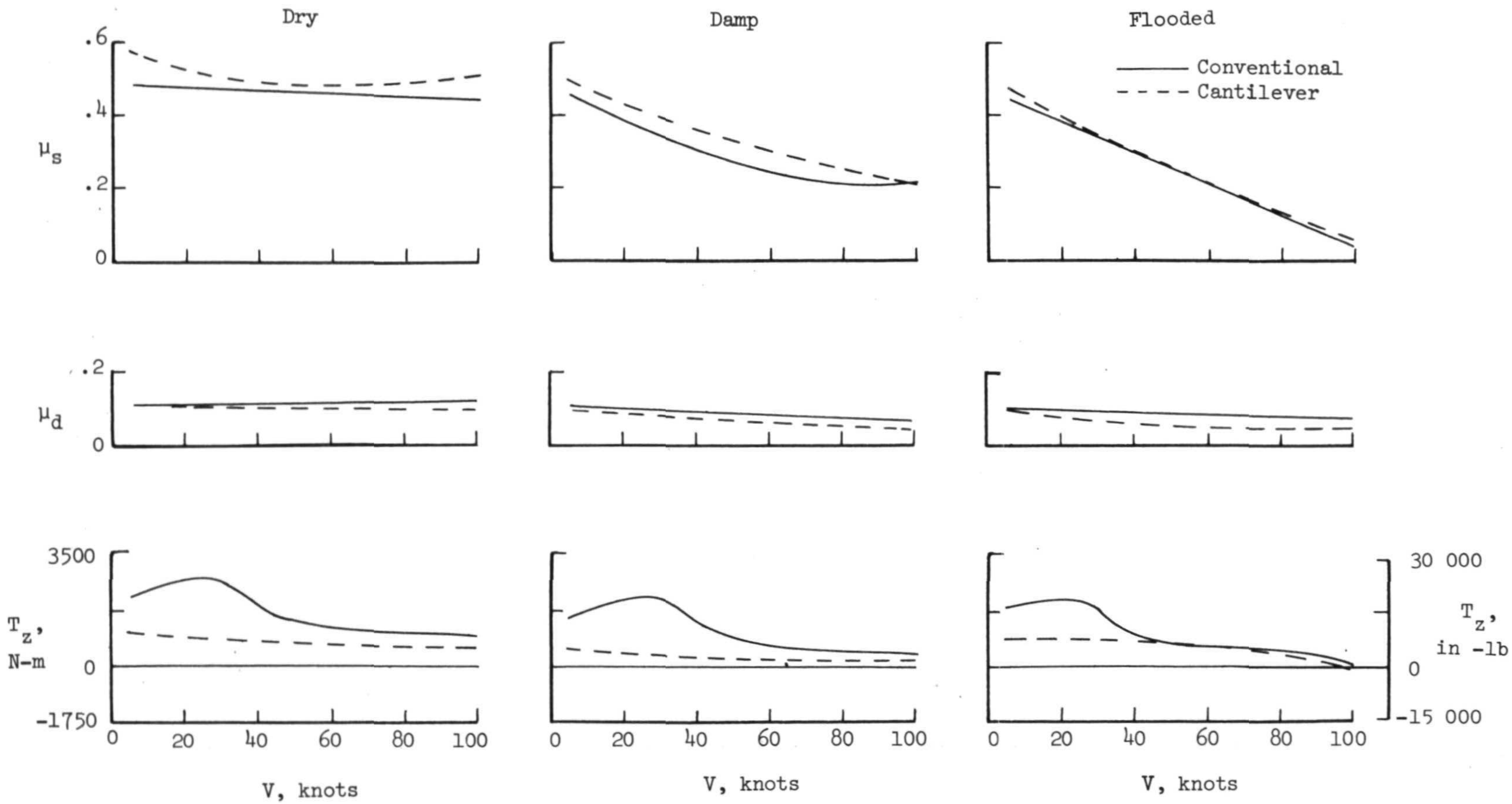


Figure 11.- Effect of ground speed on the cornering-force and drag-force friction coefficients and self-alining torque of the conventional 40 × 14-16 type VII aircraft tire and of the C40 × 14-21 cantilever aircraft tire on dry, damp, and flooded surfaces. $\Psi = 10^{\circ}$; $B_{T,D} = 0$.

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